Design of Test System for Infrared Detector and Pre-amplifier

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Abstract

A test system was introduced in this article for infrared detector and pre-amplifier based on virtual instrument technology; in which an industrial PC was utilized as main control platform, and a self-design image data acquisition and processing board, a self-design channels switch control board and some general equipments were included. Using the virtual instrument software LabVIEW 2011, the system can achieve two infrared detectors and pre-amplifiers in high/low/normal temperature test. Generally, a sliding window with the 3σ principle method is used to detect blind pixels, but this method has a defect which may not detect some blind pixels. A new blind pixels detection method was proposed in this paper based on an enhanced 3σ principle to calculate the mean and the standard deviation excluding the maximum and the minimum in the sliding window. The simulation results showed that the proposed method is of high detection accuracy, fast lookup and accurate positioning, and is a more conducive method for hardware implementation. In practical applications, it has been proved that this system is not only of high testing precision with high degree of automation and fast test speed, but also able to meet the small signal μV level testing.

Keywords

Infrared Detector; Pre-amplifier; Blind Pixel; 3σ *Principle; Test System*

Introduction

The infrared detector is a core component of the infrared guidance missile. The pre-amplifier is an important part of the infrared detector circuit, which magnifies weak electrical signals obtained from the readout circuit and transmits the signals to follow-up processing circuit. The performance of the pre-amplifier directly affects the detecting precision of the whole infrared detector system.

Due to the influence of the material, manufacturing process, and so on, the infrared detector inevitably has some blind pixels and non-uniformity which greatly reduce the quality of the infrared image. The existence of blind pixels will reduces the SNR of infrared image, causes the false targets, and influences the follow-up image processing. There are two primary aspects to deal with the blind pixel problem, blind pixels detection and blind pixels compensation. It is crucial to detect the blind pixels correctly, because over detection can increase the amount of calculation and lose the image information; on the contrary, less detection can affect the denoising effect.

Now commonly used algorithms mainly consider two aspects of the response rate and the time domain noise. But these algorithms operate complicatedly and have a number of deficiencies. In engineering applications, the 3σ principle is generally used to detect blind pixels, but this method is easy to cause blind pixels undetected. In order to improve the performance of the infrared imaging system, a new blind detection method was proposed which uses the sliding window with an enhanced 3σ principle. The proposed method eliminates the effect of the blind pixel grey value on the mean and the standard deviation, and makes blind pixels detection more accurate and faster. This method not only is easy to be implemented with software and hardware, but also can be effectively applied to engineering projects.

Introduction of System Solutions

The test system is mainly composed of PC, image data acquisition and processing board, channels switch control board, image board, simulator, signal generator, oscilloscope, multimeter, non-point source blackbody, temperature-box, gas supply unit and other parts, as shown in Figure 1. In this system, the non-point source blackbody provides an infrared target; the gas supply unit generates gas to cool the detector; and the temperature-box provides the test environment.

First of all, the infrared detector and the pre-amplifier are linked together. The infrared target image data are passed to the image board, in the form of LVDS (Low voltage differential signaling) after preprocessing. The LVDS are acquired and stored by the image data

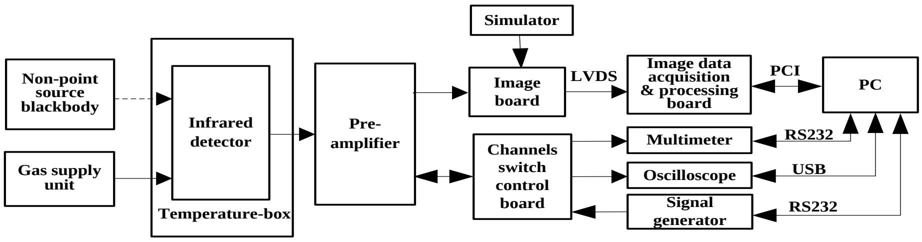

FIG. 1 SCHEMATIC DIAGRAM OF TEST SYSTEM

acquisition and processing board, at last they are transmitted to PC through the PCI bus. The PC can process, display and save these image data. In addition, it can calculate blind pixels rate and NETD. The simulator can be used to burn operating point of the image board.

Some ports voltages of the infrared detector and the pre-amplifier are measured by the multimeter through the channels switch control board. The test data are sent to the PC through RS232. And some waveforms are passed to the oscilloscope also through the channels switch control board, then sent to the PC through USB. The PC can analyze, process and save these test data. The signal generator can provide products with drive signals.

Blind pixels Detection Algorithm Research

Blind Pixels Definition

Blind pixels, namely invalid pixels, refer to under-responding detector unit and over-responding detector unit in IRFPA devices. An under-responding blind pixel is defined as the pixel response rate which is less than 1/10 of the average response rate of infrared focal plane array. An over-responding blind pixel is defined as the pixel response rate which is over 10 times as the average response rate of infrared focal plane array.

In order to judge a pixel whether it is a blind pixel or not, we must measure each pixel response rate and the average response rate of the infrared focal plane array. Actually, each pixel response rate is replaced by each grey value and the average response rate of the infrared focal plane array is replaced by the average grey value.

The percentage of blind pixels to total pixels is represented by the formula:

$$N_b = \frac{d+h}{M \cdot N} \times 100\% \tag{1}$$

where d is the number of under-responding blind pixels; h is the number of over-responding blind pixels; M and N respectively are representing line number and column number of IRFPA pixels, respectively.

A Sliding Window with 3σ Principle Test Method

A $(2n+1)\times(2n+1)$ window is made, and the pixel to be examined is in the center of the window. The mean and the standard deviation of all pixels in the window are calculated to judge whether the center is a blind pixel. The window's size is very important. If the window is too big, the non-uniformity influence on blind pixels detection will not be effectively eliminated. And if it is too small, the mean and the standard deviation are not very accurate.

The grey values of the infrared image based on uniform background obey normal distribution. Based on this statistical properties and the blind pixel's performance, generally the 3σ principle is used to detect blind pixels. If the difference of the center pixel grey value and the average gray value is over $\pm 3\sigma$, the center pixel is regarded as a blind pixel. The specific calculation formulas are as follows:

$$\mu_1(i,j) = \frac{1}{(2n+1)^2} \sum_{k=i-n}^{i+n} \sum_{l=j-n}^{j+n} B(k,l) \tag{2}$$

$$\sigma_1(i,j) = \sqrt{\frac{1}{(2n+1)^2} \sum_{k=i-n}^{i+n} \sum_{l=j-n}^{j+n} \left|B(k,l) - \mu_1(i,j)\right|^2} \tag{3}$$

$$e_1(i,j) = \left|B(i,j) - \mu_1(i,j)\right| \tag{4}$$

where $\mu_1(i,j)$ is the average gray value of the window which center coordinate is (i,j); n is half of window width; $B(k,l)$ is the pixel's grey value in the window; $\sigma_1(i,j)$ is the standard deviation of the window; $e_1(i,j)$ is the difference of the center pixel grey value and the average gray value.

Values of μ and σ are closely related to each gray value in the window. For example, when $n=5$ and window's size is 11×11, if the center pixel (99,74) is a blind pixel, its grey value may be the maximum or the minimum in the window. If all pixels within the

window are calculated, the gray average and the standard deviation are μ_1=22767 and σ_1=392.0 , respectively. The normal distribution curve is shown as curve 1 (real line) in Figure 2. But if the maximum and the minimum are eliminated, this will decrease the interference of blind pixels, the gray average and the standard deviation are μ_2=22802 and σ_2=68.7 , respectively. The normal distribution curve is shown as curve 2 (dashed line) in Figure 2. By comparison of two curves, if the maximum and the minimum are not ignored, the standard deviation σ is increased obviously, and the distribution curve will be more flat. This will increase the probability that blind pixels may be undetected. Therefore, eliminating the maximum and the minimum is a must.

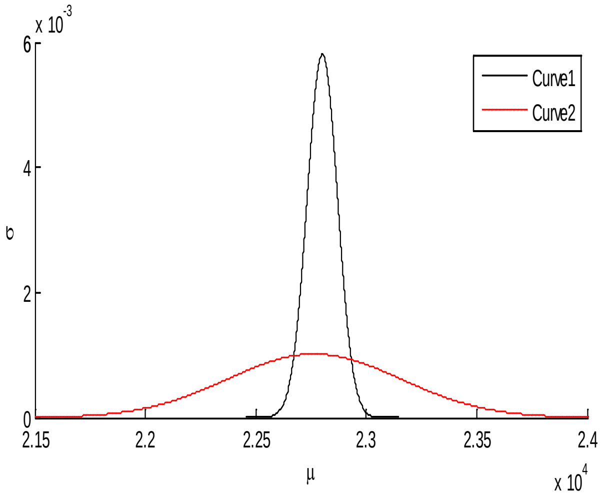

FIG. 2 THE NORMAL DISTRIBUTION CURVE OF GREY VALUES

The New Method, The Sliding Window with an Enhanced 3σ Principle Test Method.

Through the above analysis of μ and σ, eliminating the maximum and the minimum can decrease the influence of blind pixels, and it is prevented that some blind pixels may be undetected. The specific calculation formulas of the proposed method are as follows:

$$B(k_1,l_1) = \max_{(i-n)\le k,l\le(i+n)} B(k,l) \tag{5}$$

$$B(k_2,l_2) = \min_{(i-n)\le k,l\le(i+n)} B(k,l) \tag{6}$$

$$\mu_2(i,j) = \frac{1}{(2n+1)^2 - 2}\sum_{k=i-n}^{i+n}\sum_{l=j-n}^{j+n}[B(k,l) - B(k_1,l_1) - B(k_2,l_2)] \tag{7}$$

$$\sigma_2(i,j) = \sqrt{\frac{1}{(2n+1)^2 - 2}\sum_{k=i-n}^{i+n}\sum_{l=j-n}^{j+n}\left|\underset{\substack{k\ne k_1,l\ne l_1;\\ k\ne k_2,l\ne l_2}}{B(k,l)} - \mu_2(i,j)\right|^2} \tag{8}$$

$$e_2(i,j) = |B(i,j) - \mu_2(i,j)| \tag{9}$$

The flow chart of the proposed method is shown in Figure 3.

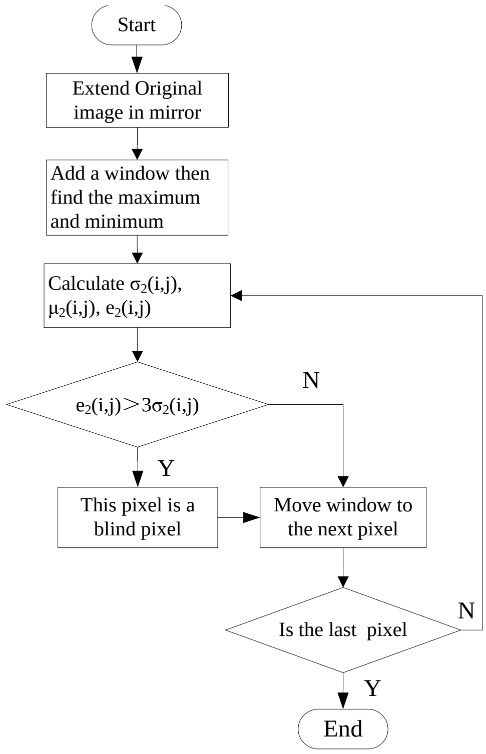

FIG.3 THE FLOW CHART OF THE PROPOSED METHOD

Test Results Analysis

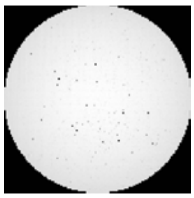

FIG.A THE ORIGINAL IMAGE

FIG.B THE ORIGINAL METHOD 11×11 WINDOW

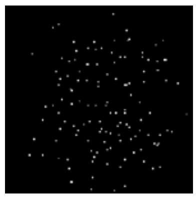

FIG.C THE NEW METHOD 11×11 WINDOW

TABLE 1 BLIND PIXELS TEST RESULTS

Window's size	Blind pixels' Number 1	Blind pixels' Number 2	σ_1(99,74)	σ_2(99,74)
3×3	0	574	1329.2	87.5
5×5	181	264	836.9	78.5
7×7	160	202	606.0	74.0
9×9	137	162	476.1	70.9
11×11	119	133	392.0	68.7
13×13	94	116	334.3	69.6
15×15	85	104	293.9	76.8

Table 1 shows the blind pixels test results. Blind pixels' Number 1 and Blind pixels' Number 2 represent blind pixels tested by the original method and the proposed method, respectively.

From Table 1, it can be seen that using the original method, with the increase of the window's size, the standard deviation σ_1 is to decrease gradually, and the number of blind pixels is also to reduce gradually. When the window's size is 3×3, the standard deviation is $\sigma_1(99,74)=1329.2$. It is too big, leading to blind pixels number detected being zero. However, using the proposed method, with the increase of the window, the standard deviation σ_2 has not changed much, and is much smaller than σ_1. The proposed method excludes the influence of blind pixels gray value to the average and the standard deviation. Therefore, the proposed method detects more blind pixels, overcomes the shortcomings of the original method, and improves the blind pixels detection. Through the analysis of data and images, when $n=5$ and the window's size is 11×11, the proposed method finds 133 blind pixels and N_b=0.81%. The result is more accurate than n given other values.

TABLE 2. THE SYSTEM CALIBRATION RESULTS

Item	V_{Z1} (mV)	I_{A3} (mA)	U_{A20} (μV)	
Nominal value	5000.0	80.00	150	100
Standard value	4999.8	80.21	162	116
Test value	4999.7	80.20	167	119
Error	0.1	0.01	5	3
Accuracy requirement	1.0	0.10	30	30

According to Table 2, it can be observed that through the calibration of the system, voltage test accuracy is up to 0.1 mV, completely satisfying the requirements of 1 mV. Current test accuracy is up to 0.01 mA, completely satisfying the requirements of 0.1 mA. And noises test accuracy is within 5 μV, also satisfying the requirements of 30 μV.

Conclusion

This article designed a test system for infrared detector and pre-amplifier based on virtual instrument technology, and proposed a new method using the sliding window with an enhanced 3σ principle for blind pixels detection. The proposed method excluded the maximum and the minimum in the window, then the mean and the standard deviation were calculated. It overcame the shortcomings of the original method which has undetected some blind pixels, and improved the performance of the blind pixels detection. In addition, the proposed method is a conducive method for hardware implementation. Through practical uses, it has been proved that the designed system can not only meet the requirement of the small signal μV level testing, but also achieve test data acquisition and processing in the form of charts and virtual panels, and realize result display and print.

REFERENCES

Chen, Dachuan, Li, Jingquan et al. "Blind Pixels Auto-Searching Algorithm for IRFPA Based on Scene." Energy Procedia Volume 17, Part B(2012): 1662–1666. doi:10.1016/j.egypro.2012.02.295.

Fang, Dan. "Information acquisition circuit technology of Infrared focal arrays." INFRARED 03(2003): 1-8.

Huang, Yingdong, An, Jianbo, Cao, Libao. "New Method of Bad Pixel detection and Compensation for IRFPA." Journal of Projectiles, Rockets, Missiles and Guidance 06(2010): 39-41.

Li, Hang. "Research of Infrared Focal Arrays Non-Uniformity Correction Algorithm." PhD diss., Huazhong University of Science and Technology, 2009.

Rogalski, Antoni. "Infrared Detectors: Status and Trends." Progress in Quantum Electronics 27(2003):59–210. doi:10.1016/S0079-6727(02)00024-1.

Rogalski, Antoni. "Progress in Focal Plane Array Technologies." Progress in Quantum Electronics 36(2012): 342–473. doi: 10.1016/j.pquantelec.2012.07.001.

Shi, Yan, Mao, Haigen, Zhang, Tianxu et al. "New Approach of IRFPA Non-effecive Pixel Discrimination Based on pixel's Characteristics Histogram Analysis." Journal of Infrared and Millimeter Waves 02(2005): 119-124.

Zhang, Xiaolong, Zhao, Guifang, Cui, Ruiqing. "Bad Pixel Detection and Compensation for IRFPA." Journal of Projectiles, Rockets, Missiles and Guidance 01(2008): 200-202.

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